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SYSTEM FOR TESTING PRESSURE PROBES USING A SIMPLE SINUSOIDAL PRESSURE GENERATOR

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SUMMARY

A pressure generator based on the Galton whistle is described. The generator is a resonant tube driven by an annular air jet. Sinusoidal pressures with peak-to-peak amplitudes of as much as 5.6 psi (3.9 N/cm^2) are achieved inside the resonator at frequencies ranging between 300 and 5000 hertz. A description of the instrumentation used for frequency, amplitude, and phase-angle measurements is given. Also discussed are the operating characteristics of the generator. A typical data plot of frequency response of a pressure probe 1 inch (2.54 cm) long with a 0.128 inch (0.325 cm) inside diameter and a volume ratio of 0.027 is given.

INTRODUCTION

Experiments to measure the dynamic stall characteristics of turbojet engines require many transient pressure measurements. These pressures are measured with probes consisting of short tubes (an inch or less in length) connected to miniature pressure transducers mounted within the probe support. In order to correlate pressure disturbances measured by probes at different locations and to identify frequencies of importance to the stall characteristics, the experimenter must know the amplitude and phase angle response of the probes with respect to frequency. The upper frequency of interest in this work is about 5000 hertz and dynamic pressure amplitudes up to 30 percent of the average pressure are anticipated.

To measure the frequency response of pressure probes and to study ways of extending the useful frequency response of such probes, a sine wave pressure generator was developed at the Lewis Research Center. This report summarizes the design and operating characteristics of this generator. The unit is capable of producing sinusoidal pressures of 5.6 psi (3.9 N/cm^2), peak-to-peak, over a frequency range from 300 to 5000 hertz. Measurements of amplitude ratio and phase angle are obtained by comparing data from the test probe with that from a reference pressure transducer mounted flush with the wall of the generator.

Some of the pressure generators are designed to meet the requirements for calibrating pressure transducers for rocket engine combustion studies where both the required pressure level and frequency range are considerably higher than the types reported in the literature (refs. 1 and 2). Transient pressure steps have been generated with shock tubes, quick opening valves and burst diaphragm devices. Determination of the amplitude and phase response against frequency using this type of generator requires a harmonic analysis of transient waveform. Various techniques for performing such analyses have been reported (ref. 1), but considerable complexity is involved both in performing the analysis and in reducing the recorded transient signal to a form suitable for analysis. Periodic pressure signals have been generated using rotating valves and flow modulators, siren tuned cavities, and piston driven devices. Some of these can produce sinusoidal waveforms if the sine wave pressure amplitude can be restricted to roughly 10 percent of the average pressure level. Wave-shape distortion occurs at higher amplitudes due to nonlinearities in the fluid properties under dynamic conditions. A sinusoidal waveform is an obvious advantage, since it eliminates the need for harmonic analysis of the measured signals. The choice of which approach is best then depends on such factors as the constancy of amplitude against frequency and the simplicity of construction and operation.

A fixed-frequency sine wave pressure generator based on a Galton whistle (ref. 3) used at Lewis is reported in an unpublished study of the infinite line pressure measuring technique. The successful use of this device and its inherent simplicity prompted the development of the variable-frequency generator reported herein. The following sections describe the design and operating characteristics of the generator, the instrumentation used to measure the frequency response of probes, and typical test results.

DESCRIPTION OF PRESSURE GENERATOR

A drawing of the pressure generator is shown in figure 1. The resonator is made from 1-inch (2.54-cm) outside-diameter tube of 0.065-inch (0.17-cm) wall thickness and is 12 inches (30.5 cm) long. The open end of the tube is tapered at 30° with respect to the tube axis to form a sharp edge. The resonant frequency is adjusted by moving the tuning piston. The tuning piston is 0.865 inch (2.2 cm) in diameter. Pressure measuring ports are located along the length of the resonator tube. Three ports are used at each axial station: one

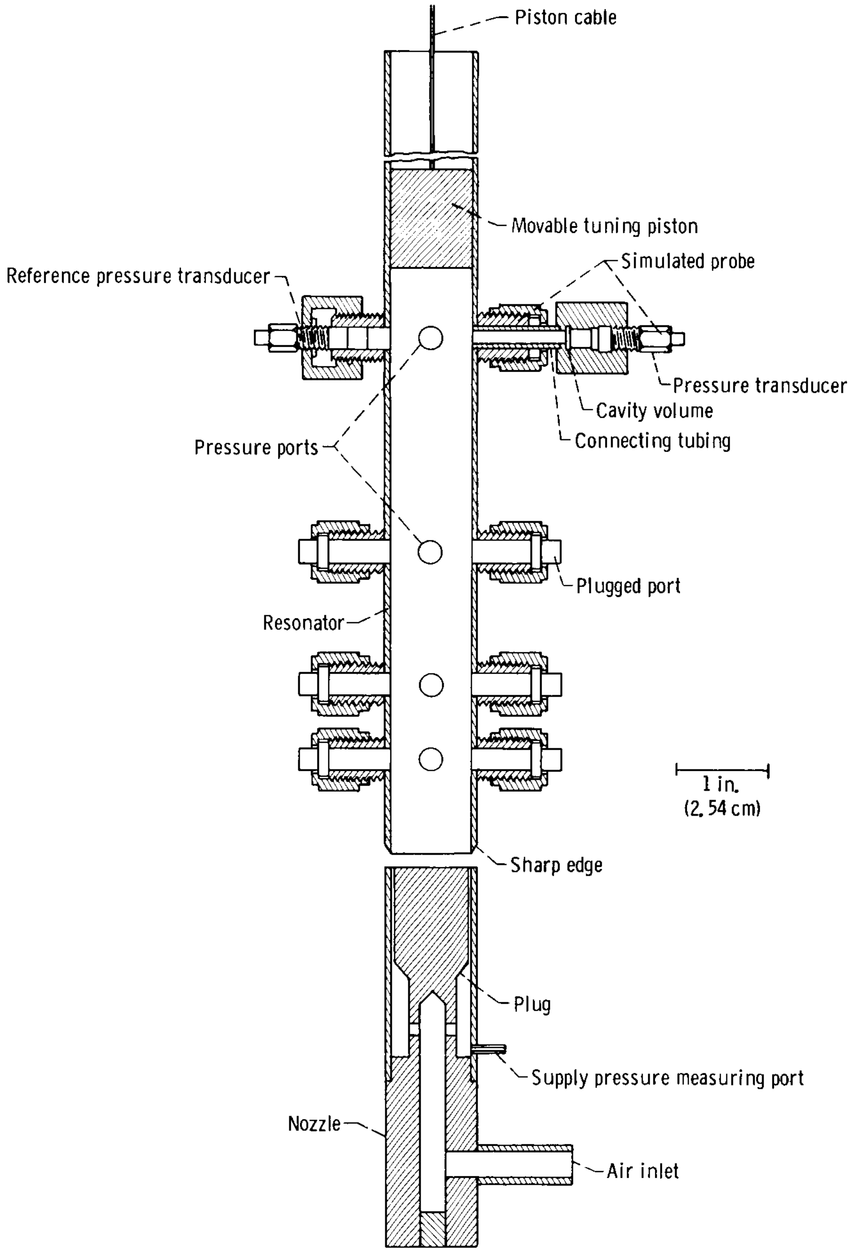


Figure 1. - Pressure generator.

for the test probe, one for a reference transducer, and a spare. Ports at more than one axial position are required in order to cover the frequency range. The number of axial positions for the ports and their axial location will be discussed in the next section. As shown in figure 1, unused ports are blocked with plugs that are flush with the inner wall of the resonator tube. Also shown in figure 1, are the reference transducer and a simulated test probe. The nozzle is made from tubing the same diameter as the resonator and is 2.25 inches (5.7 cm) long. A plug is fitted inside this tube and machined to make an annular passage for air flow. The annulus is 0.03 inch (0.076 cm) thick. The end of the plug and nozzle tube are machined flat and perpendicular to the nozzle axis. Nozzle to resonator tube spacing is adjustable between 0.01 and 0.5 inch (0.025 and 1.27 cm).

A photograph of the pressure generator is shown in figure 2. Because of the high

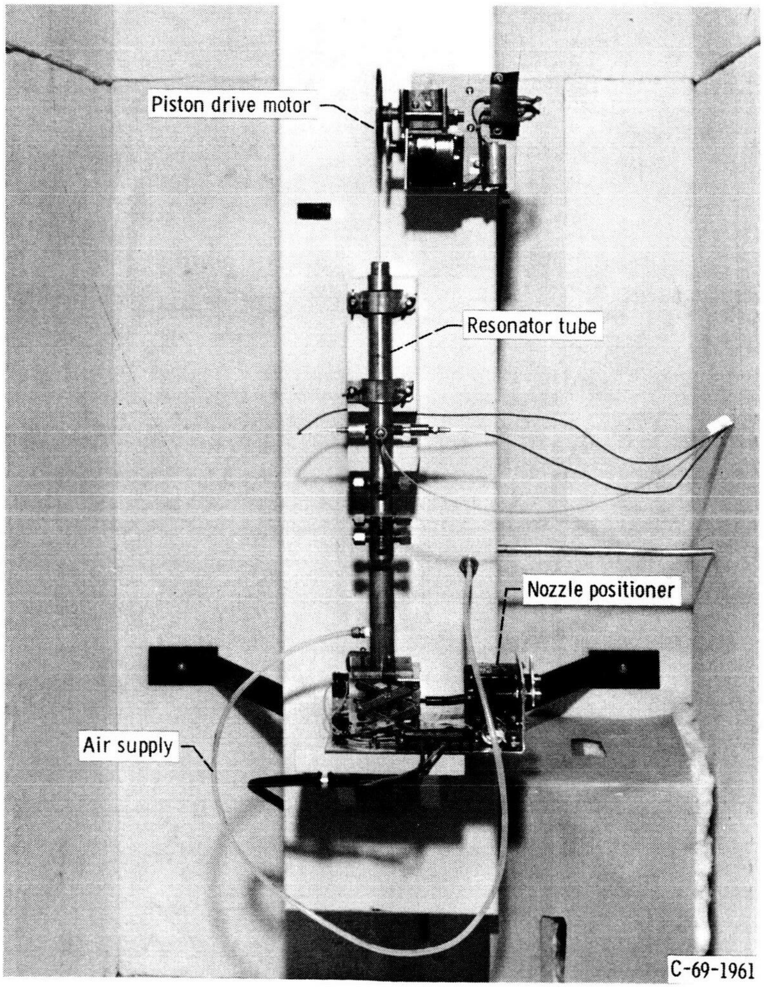


Figure 2. - Pressure generator installed in test cell.

sound levels developed by the generator, it is operated within a sound proof enclosure. The tuning piston position is remotely controlled by an electric motor. Also, the nozzle-to-resonator spacing is varied by use of a motor driven laboratory jack. Air is supplied through an adjustable regulator at pressures from 0 to 5 psi (0 to 3.4 N/cm^2) to drive the generator.

OPERATING CHARACTERISTICS

Air flows through the nozzle annulus and impinges on the sharp edge of the resonator. The resulting turbulence causes the air column inside the resonator to oscillate setting up a standing wave pattern in the resonator tube. A pressure node will always be located at the nozzle end, and a pressure antinode is always located at the piston end. The frequency of oscillation is given by

$$f = \frac{nC}{4L}$$

where

f frequency of oscillation

C speed of sound

L resonator length (distance between piston and open end of resonator)

n takes on odd values (1, 3, 5, . . . etc.)

The value which n takes on depends on the oscillation mode. This will vary depending on supply pressure and the spacing between the nozzle and resonator. Occasionally, n takes on values as high as seven as supply pressure was varied between 0 to 5 psi (0 and 3.4 N/cm^2), and spacing between 0.25 and 0.01 inch (0.63 and 0.025 cm). Thus, for any given piston position (or length L) as many as seven different frequencies could be stably maintained.

As the oscillation mode changes, other pressure nodes and antinodes appear within the resonator tube. Thus, the position of the sets of pressure measuring ports is dictated by the requirement that a set of ports be available in the vicinity of a pressure antinode for any frequency and oscillatory mode used. The axial positions of the four sets of pressure ports shown in figure 1 were determined such that, with the generator operating in the first mode (n = 1), a pressure tap would be available where the pressure is within 75 percent of the maximum pressure.

In operation, the pressure amplitude and wave shape can be varied by adjusting the nozzle supply pressure and/or the nozzle-to-resonator-tube spacing. For a constant spacing, increasing supply pressure will cause the sinusoidal pressure amplitude to increase to a point at which wave-shape distortion becomes apparent. This distortion is primarily associated with the next higher or lower resonant frequency of the generator. As the supply pressure is further increased, more distortion is introduced until the frequency of oscillation suddenly shifts to that of the next higher mode. Oscillation in this new mode is stable, and a pressure level can be found which results in a minimum of wave-shape distortion. On increasing the supply pressure still further, the pressure amplitude increases, distortion is introduced, and a shift to the next higher oscillatory mode occurs. Similar effects occur if the nozzle-to-resonator-tube spacing is decreased while supply pressure is held constant.

Tests have been run to determine some of the more pertinent operating characteristics of the generator. For all measurements, the nozzle supply pressure and spacing were adjusted for minimum wave-shape distortion as indicated by an oscilloscope trace. In figure 3, the pressure amplitude (peak to peak) achieved in the generator is shown plotted as a function of nozzle supply pressure. Also shown plotted is the static-pressure level measured at the face of the tuning piston as a function of nozzle supply pressure. Tests have shown that the pressure amplitudes measured at each port in a set of ports were equal to within the estimated accuracy of the measurement (1 percent).

Frequency spectrum analyses have been made of the generated pressure-wave shape. When operating in the first mode (n = 1), the third harmonic distortion (fre-

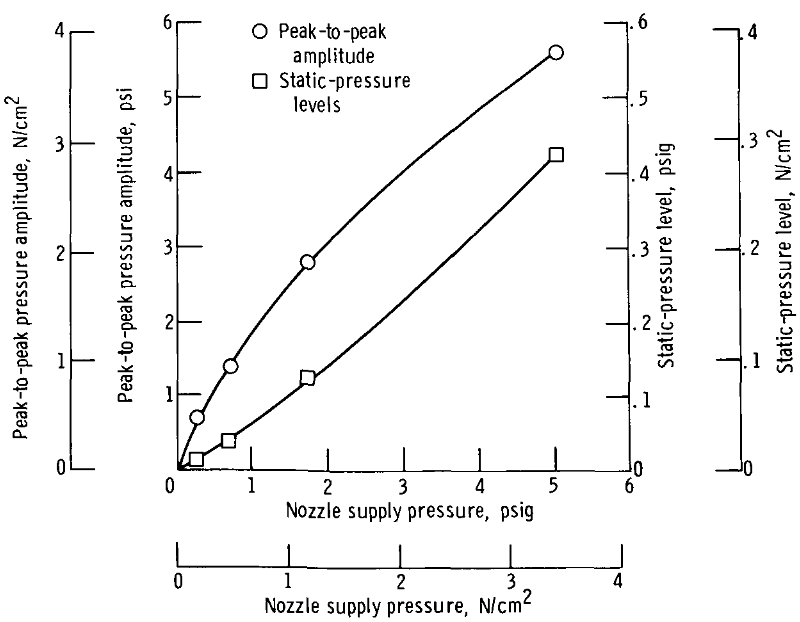
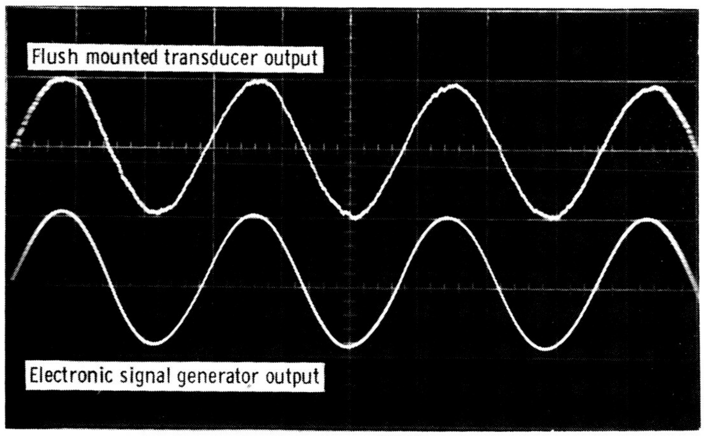
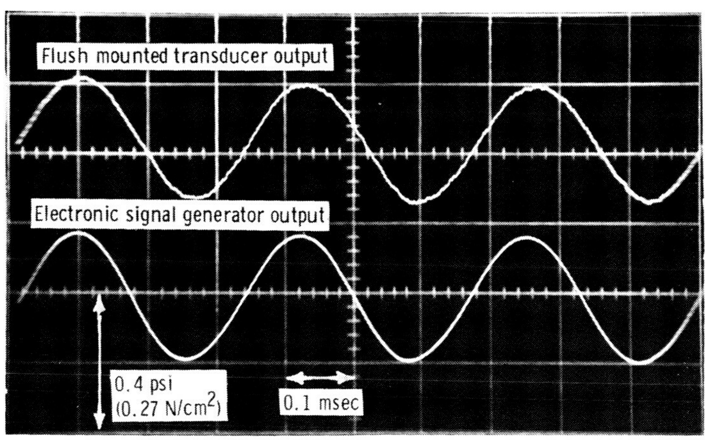


Figure 3. - Peak-to-peak sinusoidal pressure amplitude and static-pressure level as function of nozzle supply pressure over frequency range from 350 to 4500 hertz.

quency associated with the n = 3 mode) was present in amounts ranging from 1 percent of the fundamental at 0.7 psi (0.5 N/cm^2) peak to peak to 4 percent at 5.6 psi (3.9 N/cm^2) peak-to-peak amplitude. When operating in the third mode (n = 3), distortion was approximately 3 percent of the fundamental and was associated with the frequency of the first mode (n = 1). Two typical oscilloscope tracings of the generator output measured at different frequencies with a flush mounted miniature quartz pressure transducer is shown in figure 4. Also shown for comparison is a sine wave obtained from an electronic signal generator tuned to the same frequency.



Frequency, 351 Hz



Frequency, 3010 Hz

Figure 4. - Oscilloscope tracings of pressure wave shape.

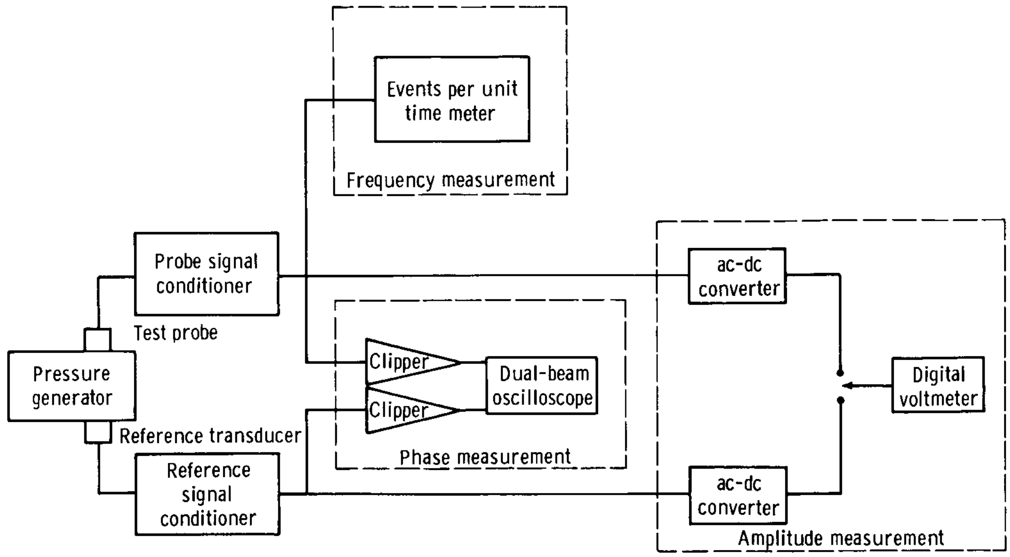


Figure 5. - Instrumentation schematic.

INSTRUMENTATION

Instrumentation has been set up in conjunction with the pressure generator to measure pressure amplitude, frequency, and the phase angle between the probe under test and a flush mounted reference transducer. A schematic diagram of the instrumentation is shown in figure 5. Initially, the test probe and reference transducer's signal conditioners are adjusted so that equal voltage outputs are obtained for equal pressure inputs to the transducers. For amplitude measurements, the conditioned signals are converted from alternating to direct current and measured with a digital voltmeter. Frequencies are measured using an events per unit time counter (EPUT meter).

The phase angle measurement is made by measuring the relative time delay between a positive zero crossing of the test probe signal and that of the reference transducer. First, the signals from the test probe and reference transducer are amplified and clipped to produce square waves. This is accomplished using standard operational amplifier techniques. The squared outputs of the reference and probe transducer are viewed on a dual beam oscilloscope. The scope is triggered on the zero crossing of the reference transducer. The sweep rate of the scope is adjusted for each test frequency so that either a half or a full wave of the reference signal fills 0.9 of the scope screen. In this manner, the horizontal axis is calibrated in degrees, either 200 or 400 depending on whether a half or a full wave length occupies 0.9 of the scope screen. The point of zero crossing of the test probe along the horizontal axis then gives the phase of the probe with respect to the reference transducer.

This phase angle measuring technique allows the operator to visually average a reading and remove the effects of jitter and noise included in the signals. It was found that this jitter was sufficient to preclude the use of an automatic phase measuring system which made use of a digital counter.

Estimated error for the measurements just described are ±1 percent of the reading for amplitude measurements, ±1 hertz for the frequency measurement, and $\pm 5^{\circ}$ for a phase measurement.

TYPICAL PROBE RESPONSE DATA

The pressure generator has been used to determine the response of a number of probe configurations. One such simulated probe is shown mounted in the generator of figure 1. It consists of a 1-inch (2.54-cm) long tube with a 0.128-inch (0.325-cm) inside diameter and a volume ratio of 0.027. This is the ratio of the volume of the cavity located in front of the transducer to the tube volume. A plot of the response of this probe is shown in figure 6. These measurements were made at peak-to-peak pressure amplitudes of 0.7 psi (0.5 N/cm^2) thereby reducing the effects of wave-shape distortion on the transducer response. Plotted are two sets of test data of amplitude ratio (in dB)

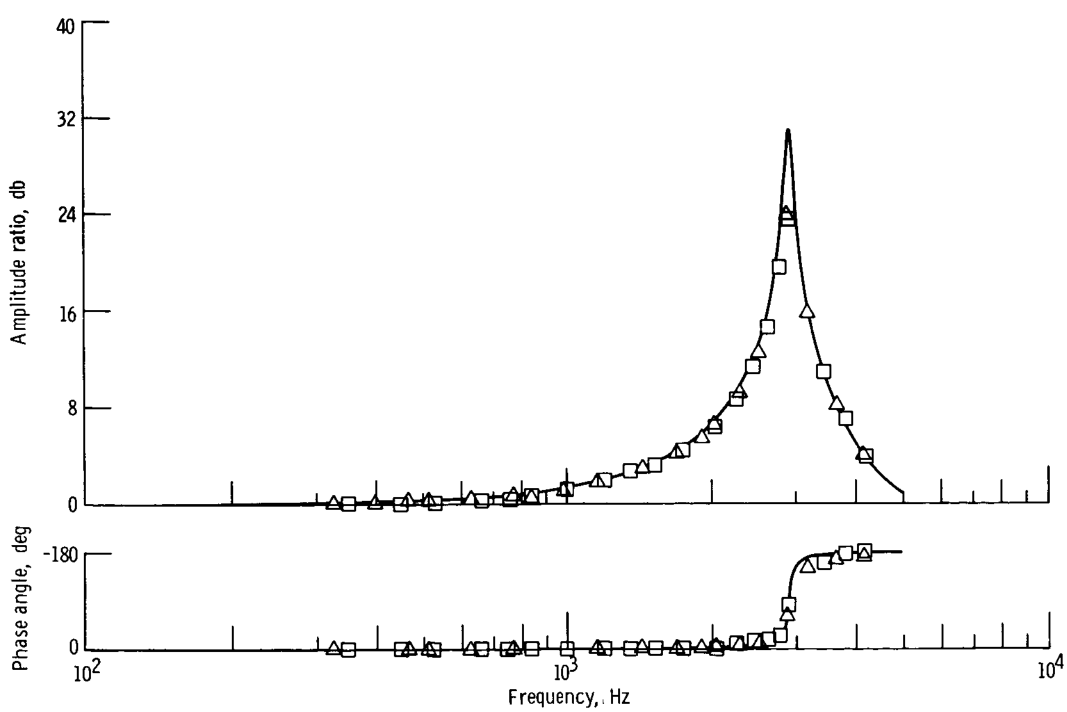


Figure 6. - Frequency response of simulated probe. Probe length, 1 inch (2.54 cm); inside diameter, 0.128 inch (0.325 cm); volume ratio, 0.027.

and phase angle as a function of frequency. The two sets of data were taken approximately 60 days apart indicating the repeatibility of the probe, pressure generator, and instrumentation. Also plotted in figure 6 is a theoretical curve calculated for this probe from an equation derived by Iberall (ref. 4). An end correction of $8D/3\pi$ was applied to the tube length for this calculation where D is the tube diameter. Approximately 30 data points can be taken in 1 hour with this test arrangement.

It has been found that, when testing lightly damped probe configurations (e.g., fig. 1), data cannot be taken within about ±3 percent of the resonant frequency. In cases such as this, the frequency of the generator will flip from a stable condition below the resonant frequency to a stable condition above the resonant frequency. This is a result of impedance effects between the test probe and resonator tube.

CONCLUDING REMARKS

A pressure generator capable of producing sinusoidal pressures at amplitudes to 5.6 psi (3.9 N/cm^2), peak to peak, and frequencies between 300 and 5000 hertz has been described. The generator consists of a resonant tube driven by an annular jet. Oscillating modes other than that of the quarter wavelength can be stably maintained. A moveable piston is used for frequency adjustment. The generator is designed to measure the frequency response of pressure probes, but may also find use in testing of fluidic and other devices. Typical test data indicate that good repeatibility of the generator and instrumentation has been obtained.

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16. Abstract

A simply built and easily operated pressure generator is described which is capable of producing sinusoidal pressures at frequencies ranging between 300 and 5000 Hz and peak-to-peak amplitudes to 5.6 psi (3.9 N/cm^2). The generator design is based on the Galton tube which is a resonant tube driven by an annular air jet. Instrumentation for making frequency, amplitude, and phase angle measurements is described. A typical data plot of the frequency response of a pressure probe is given.

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